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THE USE OF OPAQUE LOUVRES AND SHIELDS TO REDUCE REFLECTIONS WITHIN THE COCKPIT: A TRIGONOMETRICAL AND PLANE GEOMETRICAL APPROACH

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Opaque shields can be used to channel light and thereby reduce reflections within the cockpit. These shielding devices range from the standard glare shield on top of the instrument panel to the more experimental use of Light Control Film[R] and Micromesh[R] for this purpose. Because of the need to determine the best position, width, spacing, etc. of these shielding devices, it was felt that a systematic approach would be highly desirable. This work describes a mathematical analysis to assess the applicability of those devices to resolve aircraft windscreen reflection problems.

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SUMMARY

Opaque shields can be used to channel light and thereby reduce reflections within the cockpit. These shielding devices range from the standard glare shield on top of the instrument panel to the more experimental use of Light Control Film[R] and Micromesh[R] for this purpose. Because of the need to determine the best position, width, spacing, etc. of these shielding devices, it was felt that a systematic approach would be highly desirable. This work describes a mathematical analysis to assess the applicability of those devices to resolve aircraft windscreen reflection problems.

ROBERT W. BAILEY
Colonel, MSC
Commanding

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INTRODUCTION

One technique of reducing the reflections of the instruments, dials, etc. from the transparent enclosures is the use of opaque louvres and shields. In using these screening materials, one wants to maximize the extent to which they block light from reaching the canopy but minimize the extent to which they block light from reaching the pilots' eyes. This is accomplished by choosing the proper values for the position, width, spacing, and angle of these shields. The present work was inspired by the need to determine the proper thickness, i.e., louvre width, of the Light Control Film[R] which we are planning to examine as a potential means of reducing reflections within the cockpit. This film, a product of the 3M Company, consists of a thin sheet of plastic incorporating many thin louvres, .0003 inch thick and oriented normally to the surface. These sheets can be obtained in varying thickness from .015 to .030 and can be placed directly on the instrument or other source of unwanted reflections. Although this analysis was performed in connection with a specific material whose width is the only parameter that can be varied, it was made more general in order to provide a modulus for a general approach to the problem of reflection analysis in the cockpit. For example, this analysis could be used in connection with selecting the proper parameters from the standard instrument panel glare shield.

ANALYSIS

In this work we are concerned with the reflections emanating from directly above the gunner's head as viewed by the pilot (second seat). The analysis will therefore be restricted to the two-dimensional vertical plane containing the design eye and the offending portion of canopy. The method of plane geometry and trigonometry is used to set up the general formula of visibility. H represents the height of the gunner's eyes from the aircraft floor. H_c is the distance from the aircraft floor to the canopy in the plane of the gunner's eyes to the intersection of the floor with the extension of the plane of the instrument panel. H_e is the distance from the aircraft floor to the design eye.

The distance between these two shields is K and the base of the bottom shield is located a distance "a" from the intersection of the floor with the extended plane of the instrument panel. Θ is the inclination of the instrument panel with respect to the aircraft floor and α is the inclination of the louvres with respect to the instrument panel. h_1 and h_2 are the intersections of the plane of the gunner with the extensions of the plane of the louvres. d is the width of the louvres.

SOLUTION

H is divided into three ranges and a separate solution is provided for each range. These solutions are for: H below h_1 (case I),

H between h_1 and h_2 (case II), H above h_2 (case III). The dependent variable V (visibility) is the portion, from 0 to 1, of k which is visible at any height H. Figures 1, 2, and 3 show graphical representations of cases I, II, and III, respectively.

General formula

I) Case of $H < h_1$

$$V_I = k - \frac{d(h_1-H)\ (\text{Cot}\ \alpha\ \text{Cos}\ \Theta + \text{Sin}\ \Theta)}{h_1 \sec\ (\alpha-\Theta)-d-a \sin\Theta \sec\ (\alpha-\Theta) - (h_1-H)\ \text{Cos}\ \Theta\ \text{Sec}\ \alpha}$$

II) Case of $h_1 < H < h_2$

In this case, the distance between h_1 and h_2 on the pilot is $k_x \sin\alpha \csc\ (\alpha-\Theta)$ in terms of k, α and Θ.

III) Case of $H > h_2$

$$V_{III} = k - \frac{d(H-h_2)\ \text{Cos}\ (\alpha-\Theta)}{\text{Cos}\ \Theta[H-d \sin\ (\alpha-\Theta)-(k+a) \sin\Theta] + \sin\Theta[M+(k+a)\ \text{Cos}\ \Theta-d\ \text{Cos}(\alpha-\Theta)]}$$

where $h_1 = a \sin\Theta + d \sin\ (\alpha-\Theta) + \tan\ (\alpha-\Theta)\ [M+a\ \text{Cos}\ \Theta-d\ \text{Cos}\ (\alpha-\Theta)]$

$h_2 = (k+a) \sin\Theta + d \sin\ (\alpha-\Theta) + \tan\ (\alpha-\Theta)\ [M+(k+a)\ \text{Cos}\ \Theta-d\ \text{Cos}\ (\alpha-\Theta)]$

The detailed solutions for each of the above cases are demonstrated in Appendices I, II and III. The parameters α, Θ, d, a, k, and M are

all theoretically changeable but as a practical matter only d and α would normally be under our control. These two variables are therefore of particular interest. In Figure 4, V is plotted as a function of H for six different values of d. In Figure 5, V is plotted as a function of α for six different values of d and two values of H, H_e and H_c.

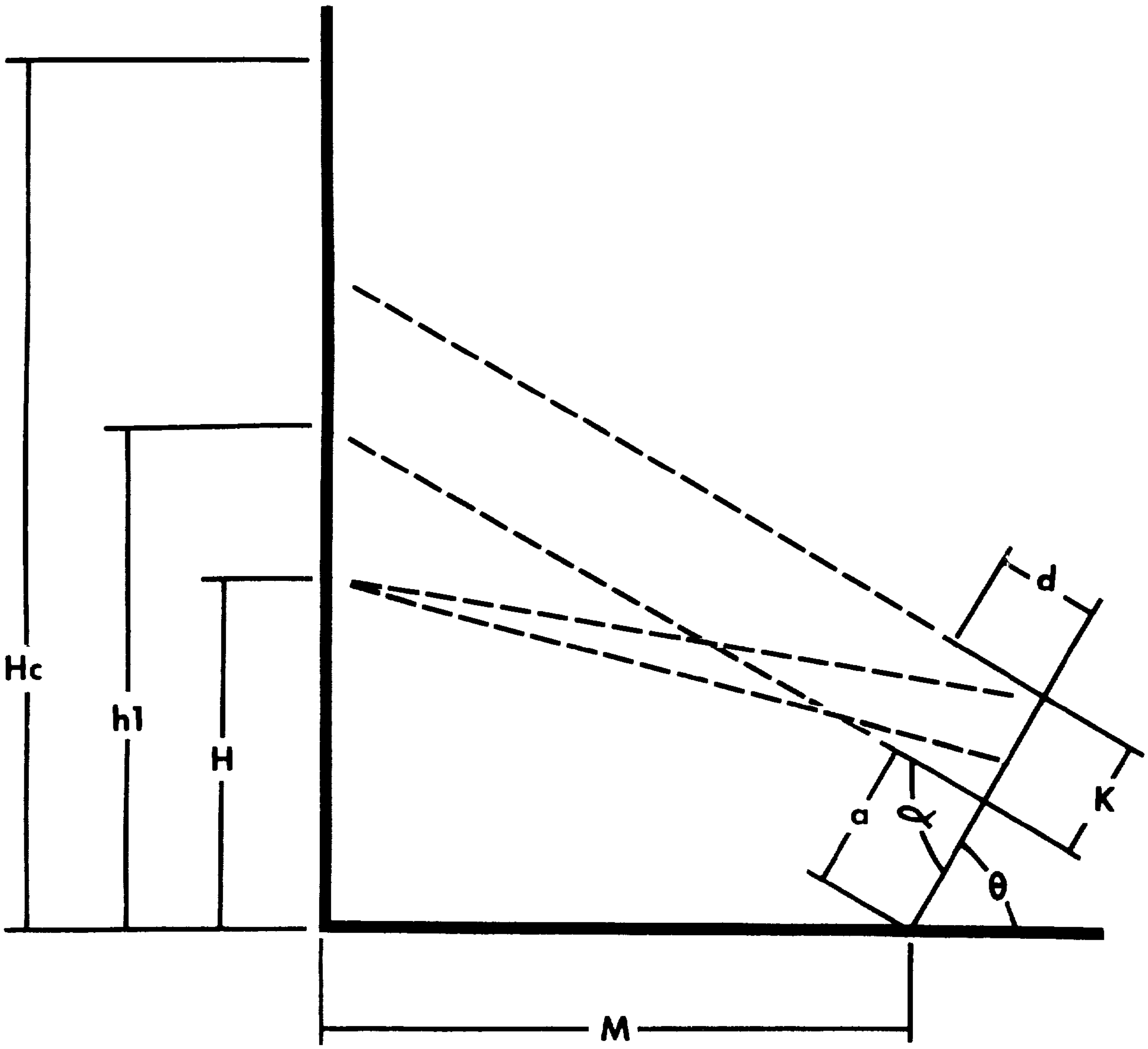
DISCUSSION AND CONCLUSION

This work has demonstrated a mathematical analysis of a specific reflection problem. We were attempting to reduce the canopy reflections above the gunner's head in an AH-1 aircraft without seriously reducing the visibility of the instruments to the gunner. It was hoped that Light Control Film[R] placed over the instrument panel would accomplish this. However, before the optimal thickness, spacing, angle, etc. of this material could be specified; it was necessary to derive the mathematical function relating visibility to height in the vertical plane containing the design eye. This report was of limited scope in that it dealt only with the reflections at a particluar place on the canopy. However, the approach demonstrated here could be extended to a full analysis of canopy reflections.

RECOMMENDATIONS

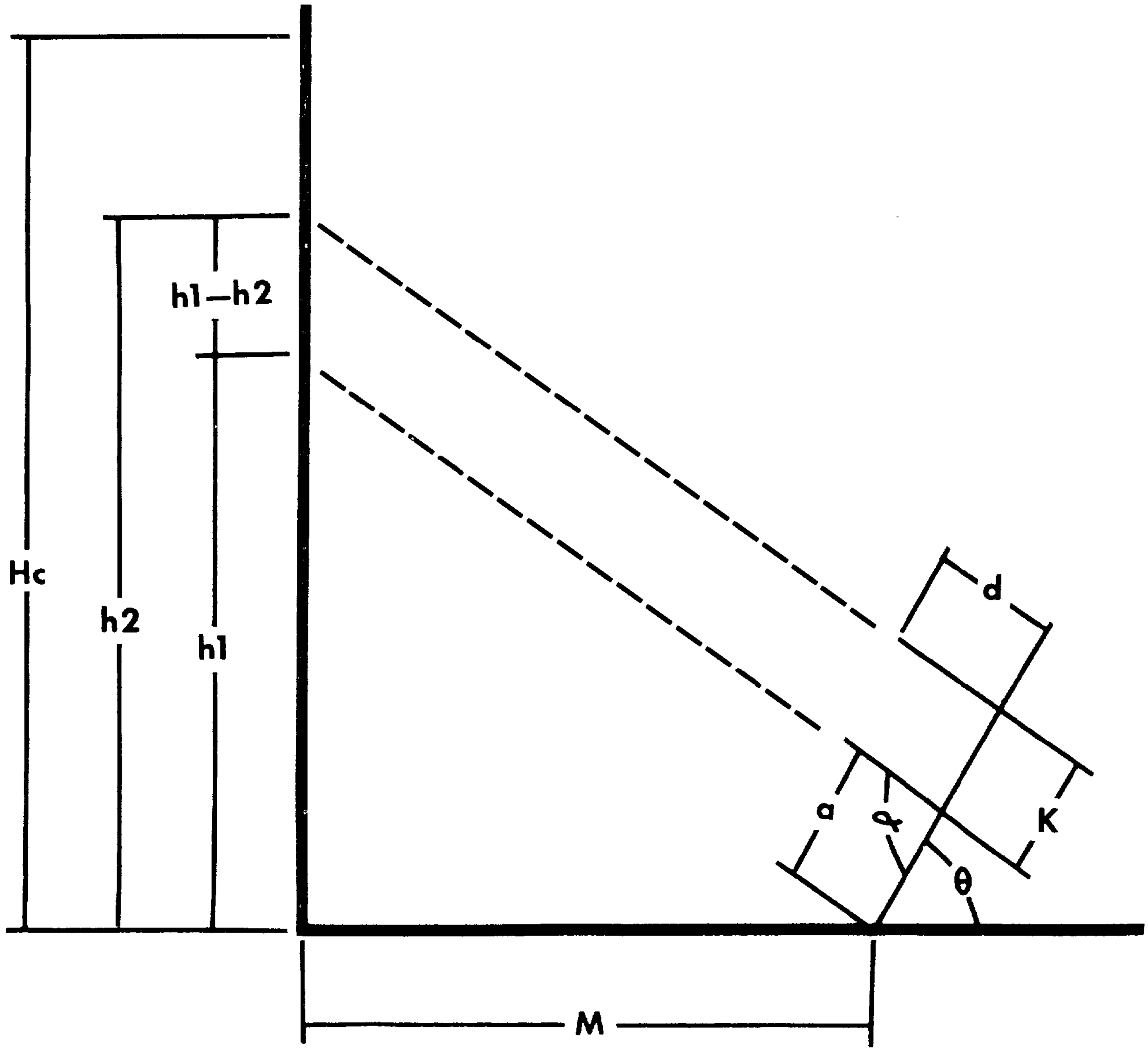
In future canopy design, it is recommended that an analysis of this sort be carried out prior to fabrication of the canopy and cockpit.

In this way, some potential reflection problems could be prevented without having to initiate costly re-designs and product improvement programs.

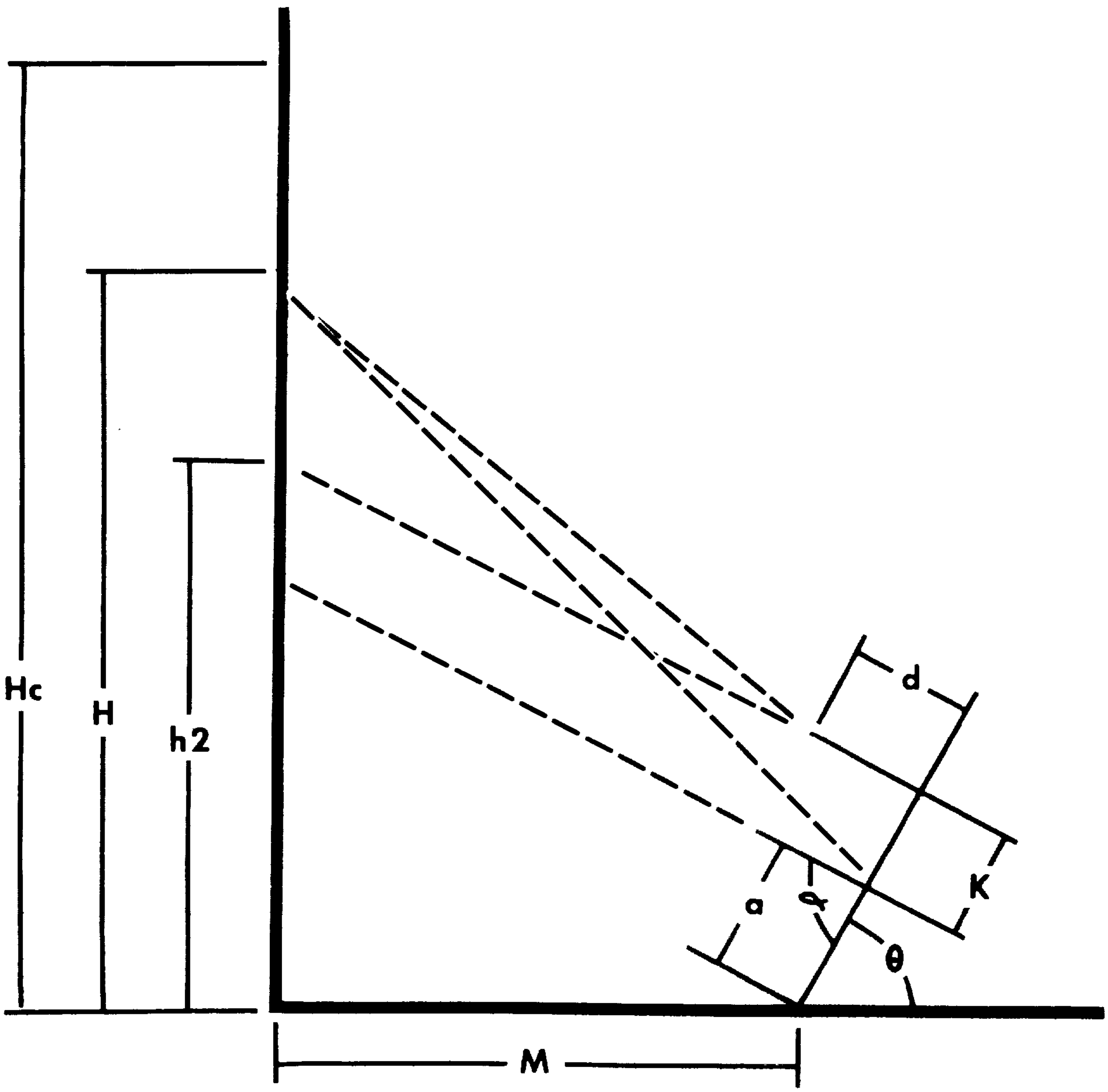


SCHEMATIC DRAWING FOR CASE 1

FIGURE 1



SCHEMATIC DRAWING FOR CASE II
FIGURE 2



SCHEMATIC DRAWING FOR CASE III
FIGURE 3

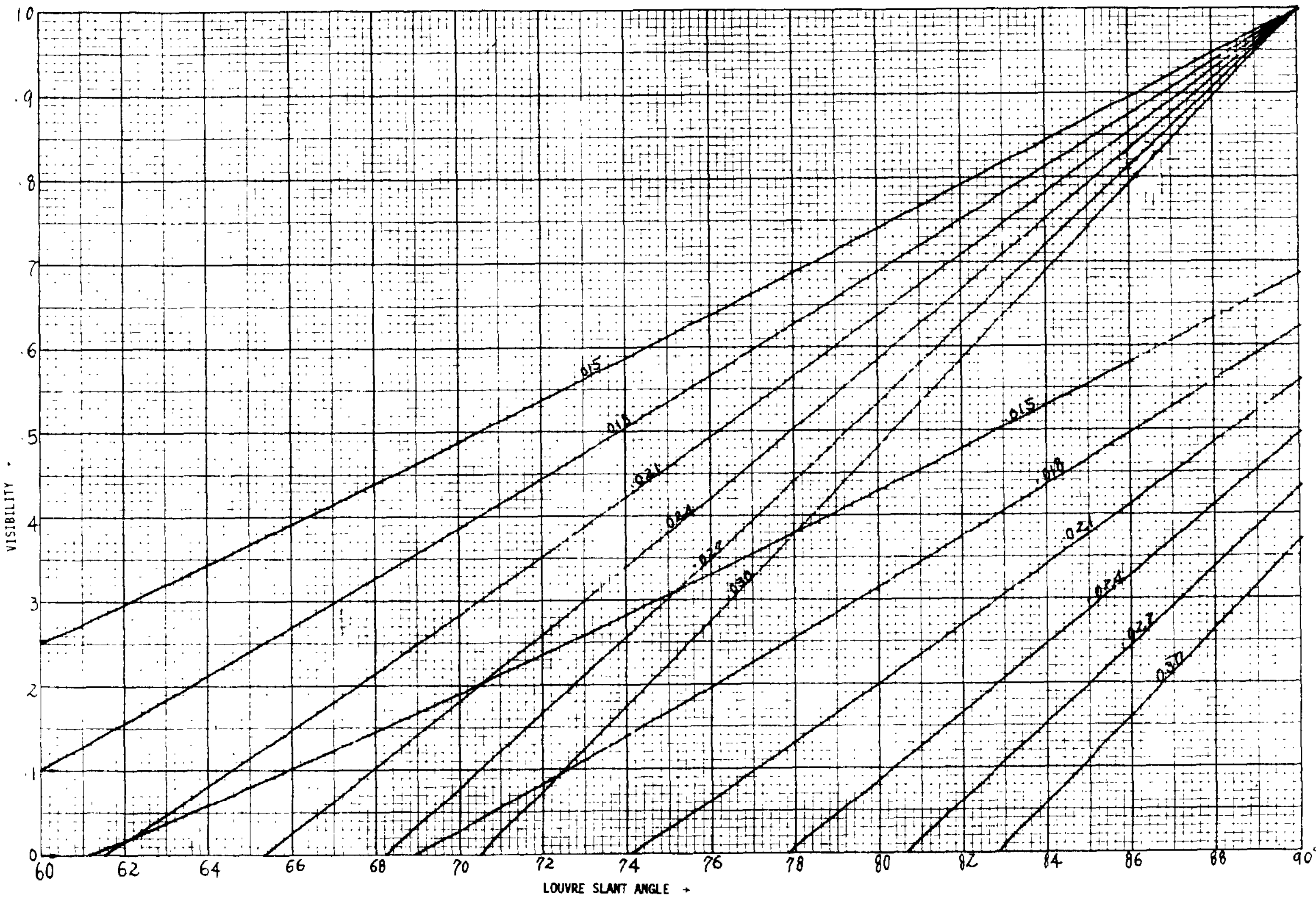


FIGURE 4. Graph of the visible portion of the instruments as a function of height in the plane of the gunner. Numbers along the X-axis are not from any existing aircraft. Each line represents a different thickness (louvre width) of Light Control Film[R].

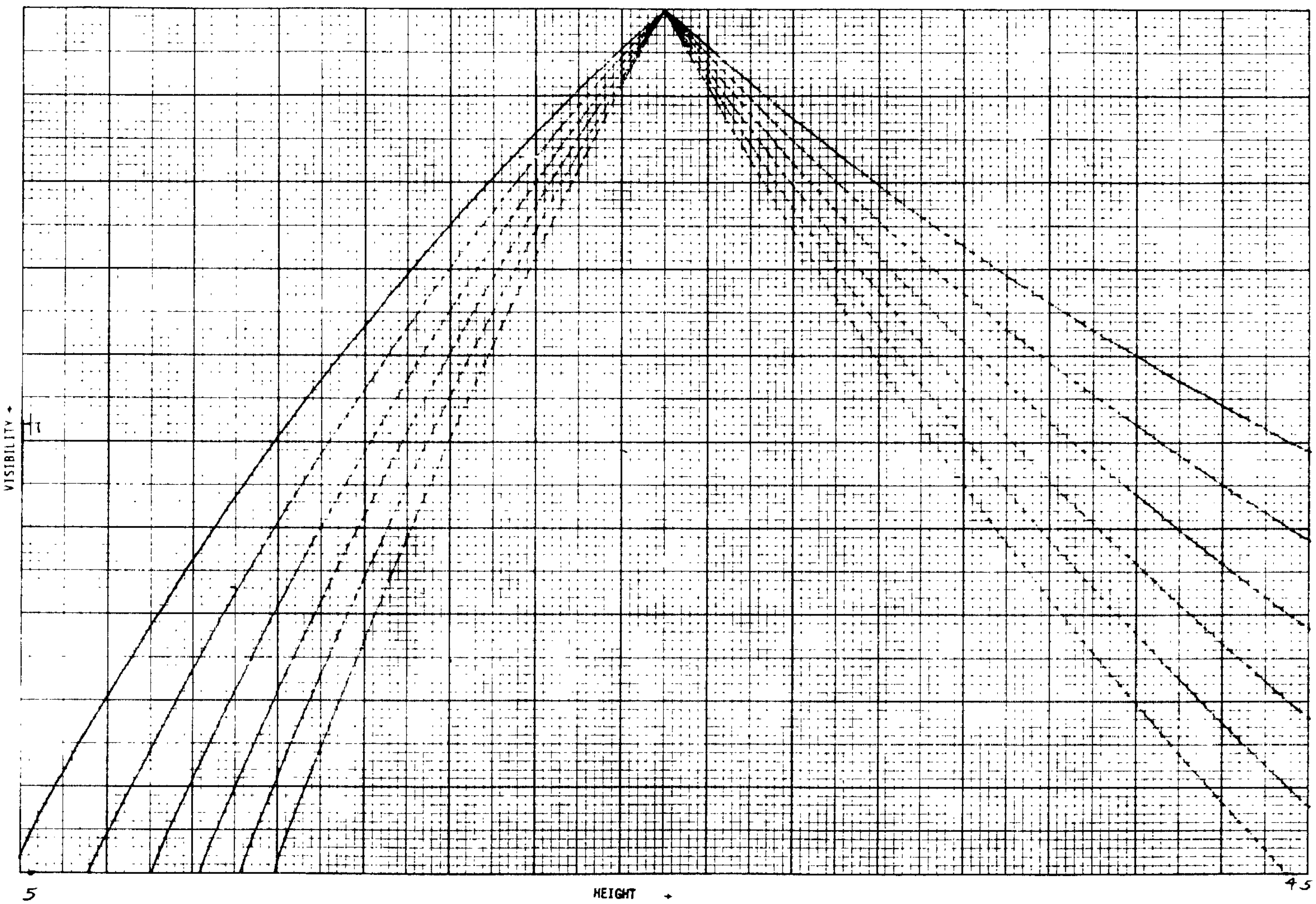
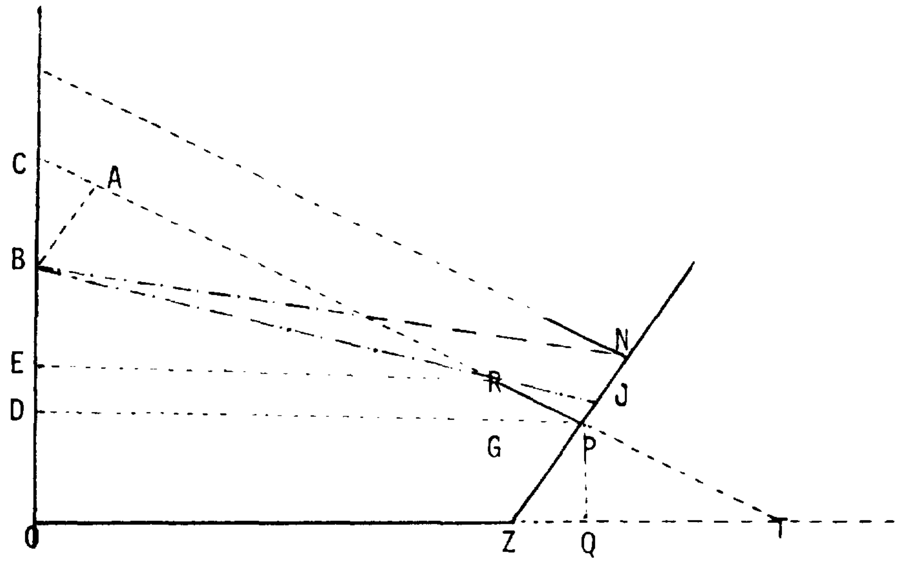


FIGURE 5. Graph showing the visible portion of the instruments as a function of slant angle of the Light Control Film[R]. The lower set of curves represents the visible portion at the height of the canopy and the upper set represents the visible portion at the height of the gunner's eyes. Numbers on the lines represent the louvre width.

APPENDIX I
CASE I

Each Point of Intersection Will Be Marked As Follows:



The involved angles and lengths are given as follows:

Angles

$<PZQ = \Theta$

$<RPZ = <CAB = \alpha$

$<PTQ = <RPG = <ARE = \alpha-\Theta (\because \overline{TO}//\overline{PD}//\overline{RE})$

$<ABC = \frac{\pi}{2} - \Theta$

$<ACB = \frac{\pi}{2} - (\alpha - \Theta)$

Length

$\overline{OZ} = M \quad \overline{PZ} = a \quad \overline{NP} = K \quad \overline{PR} = d$

$\overline{OB} = H \quad \overline{Oc} = h_1 \quad \overline{Bc} = h_1 - H$

by the Law of Trigonometry

$\overline{DO} = \overline{PQ} = a \sin \Theta \; (\because PD//OQ, \; PQ//DO)$

$\overline{GR} = \overline{DE} = d \sin (\alpha-\Theta) \; (\because ER//DG, \; GR//DE)$

$\overline{PG} = d \text{ Cos } (\alpha-\Theta), \; \overline{QZ} = a \cos \Theta$

$\overline{PT} = a \sin\Theta \sec(\alpha-\Theta)$, $\overline{PD} = \overline{QZ} + \overline{OZ} = a \cos\Theta + M$

$\overline{ER} = \overline{PD} - \overline{PG} = a \cos\Theta + M - d \cos(\alpha - \Theta)$

Since three angles and $\overline{BC}$ are given at Δ ABC, let us apply the Law of Sines.

Since $\dfrac{\overline{BC}}{\sin\alpha} = \dfrac{\overline{AB}}{\sin[\frac{\pi}{2} - (\alpha-\Theta)]}$

$$\overline{AB} = \overline{BC}\ \frac{\sin[\frac{\pi}{2} - (\alpha-\Theta)]}{\sin\alpha} = (h_1-H)\ \frac{\cos(\alpha-\Theta)}{\sin\alpha} = (h_1-H)\ \frac{\cos\alpha\cos\Theta+\sin\alpha\sin\Theta}{\sin\alpha}$$

$$= (h_1-H)\ (\cot\alpha \cos\Theta + \sin\Theta)$$

Since $\dfrac{\overline{BC}}{\sin\alpha} = \dfrac{\overline{AC}}{\sin(\frac{\pi}{2} - \Theta)}$

$$AC = \frac{\sin(\frac{\pi}{2} - \Theta)}{\sin\alpha} \cdot BC = \frac{\cos\Theta}{\sin\alpha} \cdot (h_1-H) = \cos\Theta \sec\alpha\ (h_1-H)$$

At Δ COT

$$\sin(\alpha-\Theta) = \frac{\overline{OC}}{\overline{CT}} = \frac{h_1}{\overline{CT}}$$

therefore $\overline{CT} = h_1 \sec(\alpha-\Theta)$

$$\overline{AR} = \overline{CT} - \overline{TP} - \overline{PR} - \overline{AC} = h_1 \sec(\alpha-\Theta) - a \sin\Theta \sec(\alpha-\Theta) - d$$
$$- (h_1-H) \cos\Theta \cdot \sec\alpha.$$

Because JP//AB and three corresponding angles are the same at ΔJPR and ΔARB

$\Delta JPR \sim \Delta ARB$

hence PR, JP, JR $\sim$ AR, AB, BR

therefore $\frac{\overline{AR}}{\overline{PR}} = \frac{\overline{AB}}{\overline{JP}}$

$$JP = \frac{\overline{PR}.\overline{AB}}{\overline{AR}} = \frac{d.\ (h_1-H)\ (\text{Cot}\alpha\ \text{Cos}\Theta + \text{Sin}\Theta)}{h_1\ \text{Sec}\ (\alpha-\Theta) - a\text{Sin}\Theta\ \text{Sec}\ (\alpha-\Theta) - d - (h_1-H)\ \text{Cos}\Theta\ \text{Sec}\ \alpha}$$

Visibility is as follows:

$$V = \overline{NP} - \overline{JP} = K - \frac{d(h_1-H)\ (\text{Cot}\ \alpha\ \text{Cos}\ \Theta + \text{Sin}\ \Theta)}{h_1\ \text{Sec}\ (\alpha-\Theta) - a\text{Sin}\Theta\ \text{Sec}\ (\alpha-\Theta)-d-(h_1-H)\ \text{Cos}\Theta\ \text{Sec}\alpha}$$

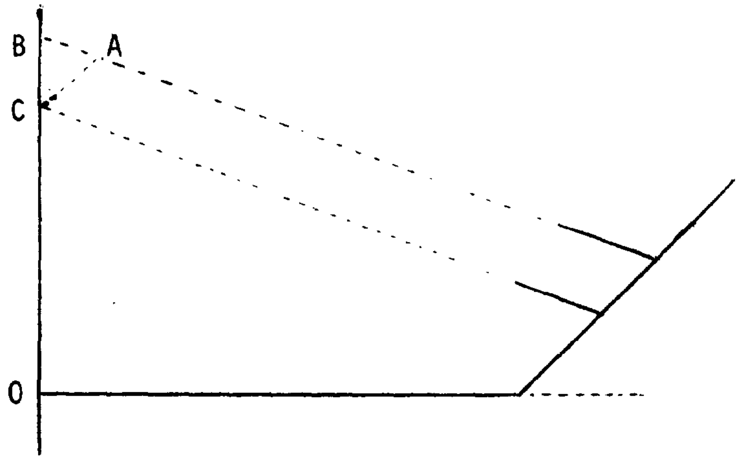
Here h_1 can be stated in terms of Θ, α, a, d

$$h_1 = \overline{OE} + \overline{DE} + \overline{BD} = a\text{Sin}\Theta + d\text{Sin}\ (\alpha-\Theta) + ER.\ \tan\ (\alpha-\Theta)$$

$$= a\text{Sin}\Theta + d\text{Sin}\ (\alpha-\Theta) + \tan\ (\alpha-\Theta)\ [M + a\text{Cos}\Theta - d\text{Cos}\ (\alpha-\Theta)]$$

APPENDIX II

CASE II



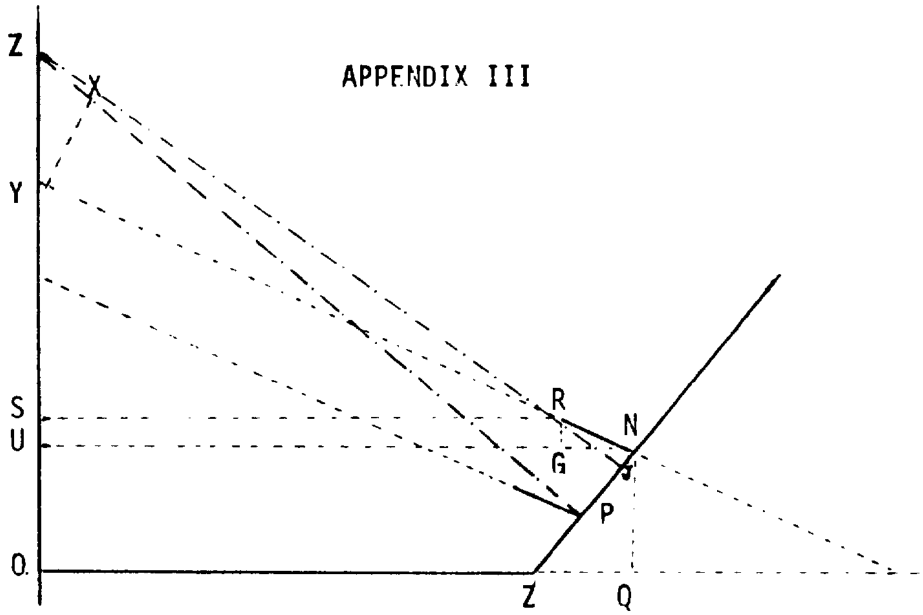
Since <A, <B, <C are given in Appendix I and $\overline{OC} = h_1$ and $\overline{OB} = h_2$,

$\overline{BC}$ can be expressed in terms of k, α, Θ

$$\overline{BC} = h_1 - h_2 = k \operatorname{Sin}\Theta \ \operatorname{CSC}(\alpha-\Theta)$$

APPENDIX III

CASE III



Angles and lengths are as follow:

Angles

$<NZQ = \Theta$

$<RNP = <RYX = \alpha \; (\because NP//XY)$

$<NTQ = <RNG = <YRS = \alpha-\Theta \; (\overline{OT}//\overline{NU}//\overline{RS})$

$<XZY = \gamma$ (assumed)

$<ZXY = \frac{\pi}{2} - (r-\Theta)$

$<XYZ = \frac{\pi}{2} - \Theta$

Lengths

$\overline{OZ} = M \quad \overline{NZ}=\overline{NP}+\overline{PZ}=K+a. \quad \overline{NR}=d \quad \overline{OY}=H_2 \quad \overline{OZ} = H \quad \overline{ZY} = H-h_2$

By the trigometric relationship

$\overline{QZ} = (k+a) \, Cos\Theta$

$\overline{OU} = \overline{NQ} = (K+a) \, Sin\Theta \quad (\because \overline{NQ}//\overline{OU}, \; \overline{OQ}//\overline{NU})$

$\overline{NG} = d \cos(\alpha-\Theta)$

$\overline{US} = \overline{GR} = d \sin(\alpha-\Theta)$ $(\therefore \overline{GR}//\overline{US}, RS//\overline{NU})$

$\overline{NU} = \overline{OQ} = \overline{OZ} + \overline{QZ} = M + (k+a)\cos\Theta$

$\overline{RS} = \overline{NU} - \overline{GN} = M + (k+a)\cos\Theta - d\cos(\alpha-\Theta)$

$\overline{SY} = \tan(\alpha-\Theta).\ \overline{RS} = \tan(\alpha-\Theta).\ [M+(k+a)\cos\Theta - d\cos(\alpha-\Theta)]$

$\overline{RY} = \overline{RS}.\ \csc(\alpha-\Theta) = \csc(\alpha-\Theta)\ [M+(k+a)\cos\Theta - d\cos(\alpha-\Theta)]$

By the Law of Sines at ΔXYZ

Since $\dfrac{\overline{XY}}{\sin\gamma} = \dfrac{\overline{YZ}}{\sin[\frac{\pi}{2} - (\gamma-\Theta)]}$

$$\overline{XY} = \overline{YZ}.\ \frac{\sin\gamma}{\sin[\frac{\pi}{2} - (\gamma-\Theta)]} = (H-h_2).\frac{\sin\gamma}{\cos(\gamma-\Theta} = \frac{(H-h_2)\sin\gamma}{\cos\gamma\cos\Theta + \sin\gamma\sin\Theta}$$

(By the Second Cosine Law)

Since $\sin\gamma = \dfrac{\overline{RS}}{\overline{RZ}}$ $\cos\gamma = \dfrac{\overline{ZS}}{\overline{RZ}}$ at Δ ZRS

$$\overline{XY} = \frac{(H-h_2)\ \frac{\overline{RS}}{\overline{RZ}}}{\cos\Theta\ \frac{\overline{ZS}}{\overline{RZ}} + \sin\Theta.\ \frac{\overline{RS}}{\overline{RZ}}} = \frac{(H-h_2)\ \overline{RS}}{\cos.\ \overline{ZS} + \sin\Theta.\ \overline{RS}}$$

Here $\overline{SZ} = \overline{OZ} - \overline{OU} - \overline{US} = H - (k+a)\sin\Theta - d\sin(\alpha-\Theta)$

$$\therefore\ \overline{XY} = \frac{(H-h_2)\ [M+(k+a)\cos\Theta - d\cos(\alpha-\Theta)]}{\cos\Theta.\ [H-(k+a)\sin\Theta - d\sin(\alpha-\Theta)] + \sin\Theta.\ [M+(k+a)\cos\Theta - d\cos(\alpha-\Theta)]}$$

at Δ YRS

$$\overline{RY} = \overline{RS}/\cos(\alpha-\Theta) = \frac{M+(k+a) - d\cos(\alpha-\Theta)}{\cos(\alpha-\Theta}$$

Because $\overline{NJ} // \overline{XY}$ and three corresponding angles are the same at

Δ RNJ and Δ XRY

$\Delta RNJ \sim \Delta XRY$

hence $\overline{NJ}, \overline{JR}, \overline{NR} \sim \overline{XY}, \overline{XR}, \overline{RY}$

there $\dfrac{\overline{NR}}{\overline{NJ}} = \dfrac{\overline{RY}}{\overline{XY}}$

$$NJ = \overline{NR}. \frac{\overline{XY}}{\overline{RY}} = d. \frac{(H-h_2)\ \overline{RS}\ /\ \text{Cos}\ \Theta\ \ [H-(k+a)\ \text{Sin}\Theta-d\ \text{Sin}\ (\alpha-\Theta)+\text{Sin}\Theta[M+(k+a)\text{Cos}\Theta-d\ \text{Cos}\ (\alpha-\Theta]}{\dfrac{\overline{RS}}{\text{Cos}\ (\alpha-\Theta)}}$$

$$= d. \frac{(H-h_2)\ \text{Cos}\ (\alpha-\Theta)}{\text{Cos}\ \Theta\ [H-d\ \text{Sin}(\alpha-\Theta)-(k+a)\ \text{Sin}\Theta] + \text{Sin}\Theta\ [M=(k+a)\ \text{Cos}\Theta - d\ \text{Cos}\ (\alpha-\Theta)]}$$

Visibility is as follows:

$$V_{III} = \overline{NP} - \overline{NJ} = K - \frac{d\ (H-h_2)\ \text{Cos}\ (\alpha-\Theta)}{\text{Cos}\Theta\ [H-d\ \text{Sin}(\alpha-\Theta) - (k+a)\ \text{Sin}\Theta] + \text{Sin}\Theta\ [M+(k+a)\text{Cos}\Theta-d\ \text{Cos}\ (\alpha-\Theta)]}$$

Here

$$h_2 = \overline{OU} + \overline{US} + \overline{SY} = (k+a)\ \text{Sin}\Theta + d\ \text{Sin}\ (\alpha-\Theta) + \tan\ (\alpha-\Theta)\ [M+(k+a)\ \text{Cos}\Theta-d\ \text{Cos}\ (\alpha-\Theta)]$$